RDT&E Progress and Plans for Hexavalent Chromium (Cr^{6+})

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Report Documentation Page

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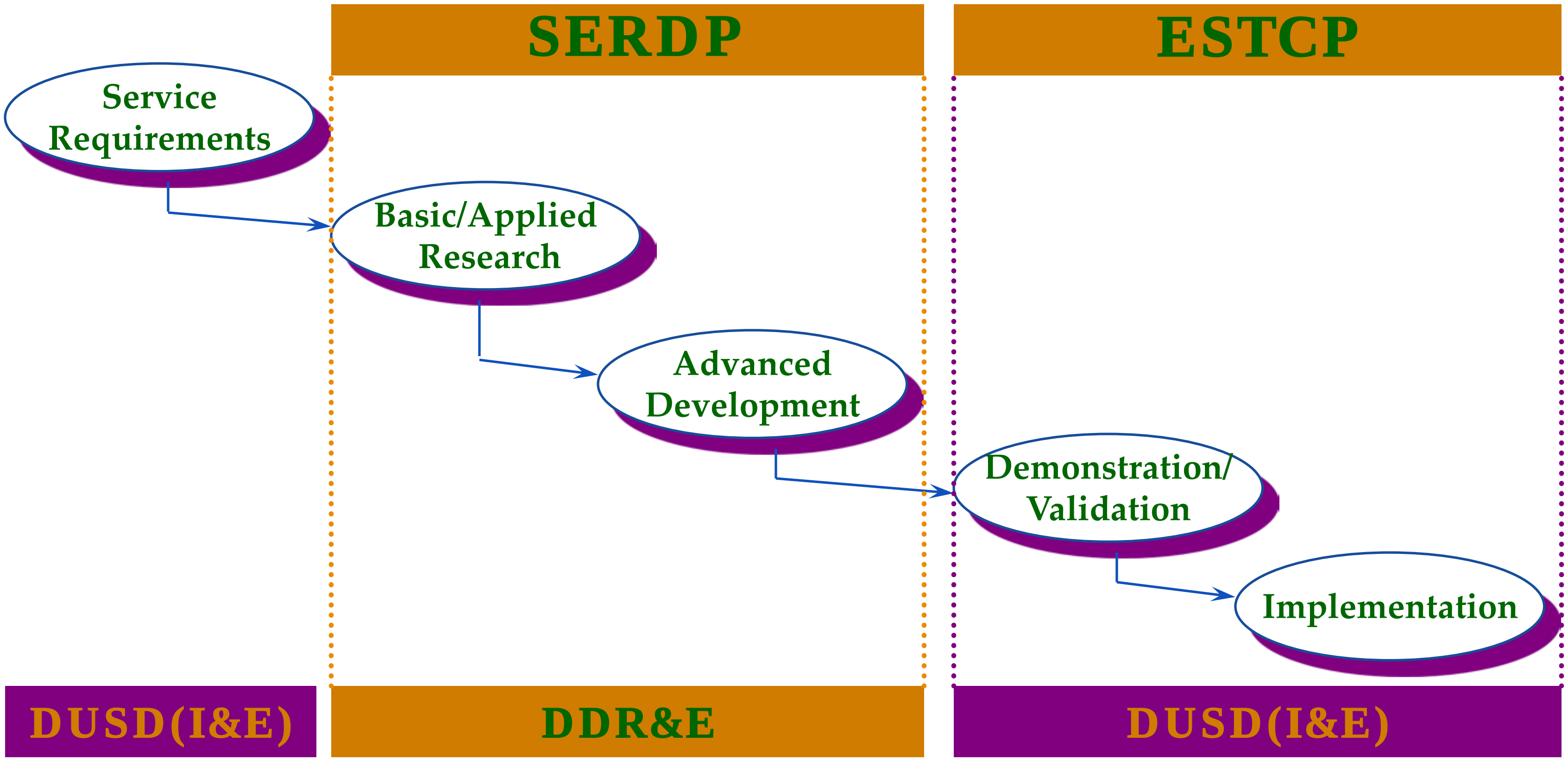
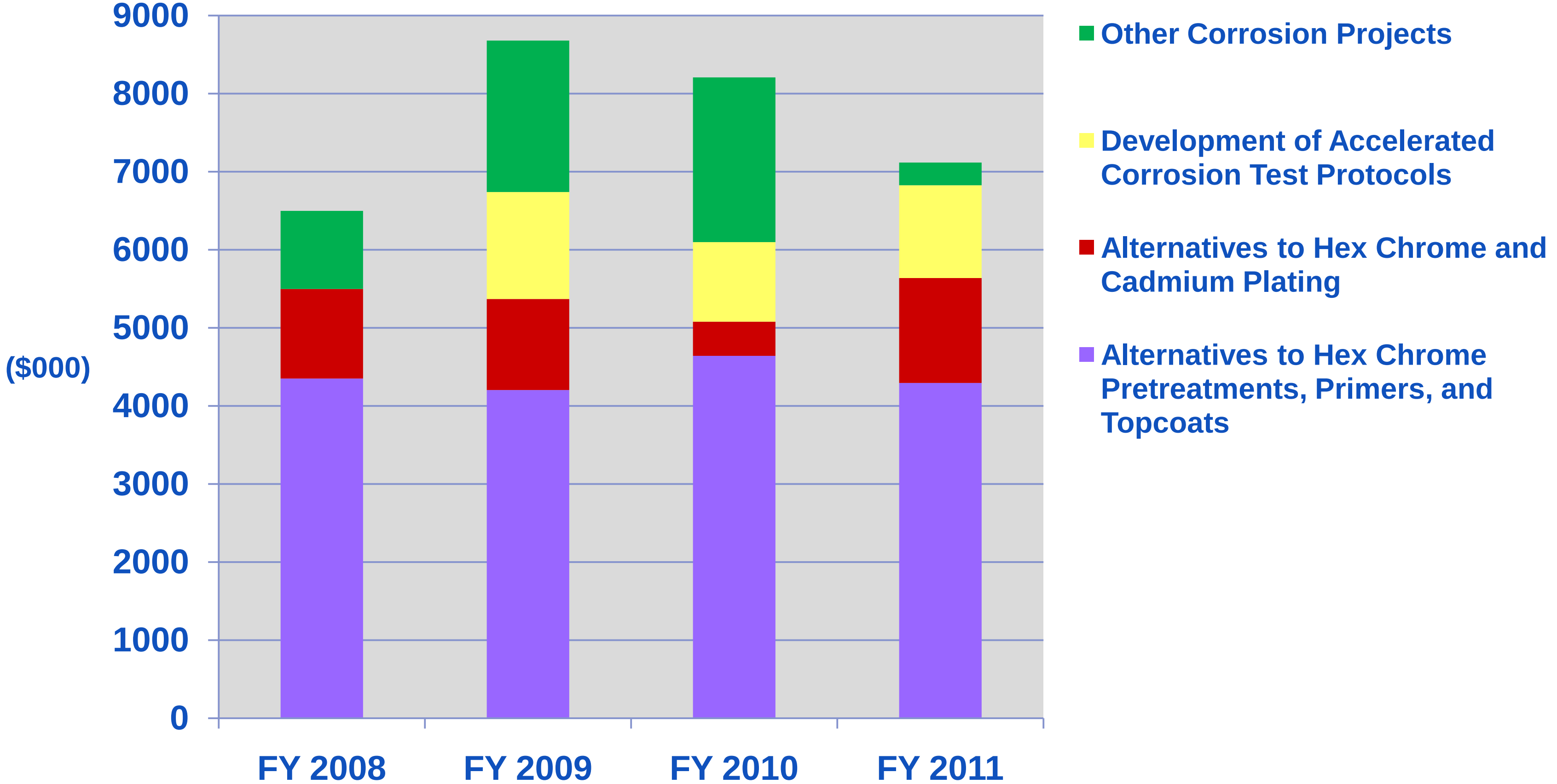
Environmental Technology Development Process



SERDP/ESTCP Investments Directly or Indirectly Related to Corrosion



Total four-year investment = ~ $ 30.2 million

Recent SERDP Cr^{6+}-Related Projects

FY2008

- **Scientific Understanding of Non-Chromated Corrosion Inhibitors Function**
  - **WP-1618:** ***Corrosion Protection Mechanisms of Rare-Earth Compounds Based on Cerium and Praseodymium*** **(Missouri University of Science and Technology)**
  - **WP-1619:** ***Morphology and Mechanism of Benign Inhibitors*** **(University of Cincinnati)**
  - **WP-1620:** ***Scientific Understanding of Non-Chromated Corrosion Inhibitors Function*** **(Ohio State University)**
  - **WP-1621:** ***Scientific Understanding of the Mechanisms of Non-Chromate Corrosion Inhibitors*** **(Southwest Research Institute)**

Recent SERDP Cr^{6+}-Related Projects

FY2009

- **Dynamic Accelerated Corrosion Test Protocol**
  - **WP-1673: *Accelerated Dynamic Corrosion Test Method Development* (Southwest Research Institute)**
  - **WP-1674: *Dynamic Multivariate Accelerated Corrosion Test Protocol* (Air Force Research Lab)**
- **Environmentally Acceptable, Direct-To-Substrate Pretreatments for Multi-Material Systems**
  - **WP-1675: *Wash Primer Replacement Based on the Superprimer Technology* (University of Cincinnati)**
  - **WP-1676: *Environmentally Friendly Zirconium Oxide Pretreatment* (PPG Industries Inc.)**

Recent SERDP Cr^{6+}-Related Projects

FY2011

- **Understanding Corrosion Protection Requirements for Adhesive Bond Primers**
  - **WP-2144:** ***Understanding Corrosion Protection Requirements for Adhesive Bond Primers*** **(NAVAIR Pax River)**

Scientific Understanding of Non-Chromated Corrosion Inhibitors Function (Project WP-1620)

Project Team – Main Performers

- **Dr. Gerald S. Frankel and Dr. Rudolph G. Buchheit**

  Fontana Corrosion Center, The Ohio State University

  Specialists in corrosion

- **Dr. Greg Swain**

  Dept of Chemistry, Michigan State University

  Specialist in electrochemistry/surface analysis

- **Dr. Mark Jaworowski**

  United Technologies Research Center

  Specialist in surface treatments

Project Team – Advisory Group

- Mr. Bill Nickerson, Naval Air Systems Command, Patuxent River, MD
- Mr. Brian Placzankis, Army Research Labs, Aberdeen Proving Ground, MD
- Dr. Joel Johnson, Air Force Research Labs, WPAFB
- Dr. Bill Fristad, Henkel Corp., Madison Heights, MI
- Dr. Joe Osborne, Boeing Phantom Works, Seattle, WA

These team members are deeply involved in the development and application of chromate-free coating systems for military applications.

Technical Objective

The primary objective of this work is to develop fundamental understanding of the existing chromate-free inhibitors and inhibitory coating systems with the ultimate goals of:

- Providing scientists and engineers developing such coatings with information that will help them improve their products.
- Providing engineers designing structures with information that will help them utilize non-chromate coating systems more effectively.

Technical Approach

Tasks/Projects

<u>Surface treatments and soluble inhibitors:</u>

1. **Fundamental studies of the Trivalent Chrome Process (TCP)**
2. **Mechanisms of selected inhibitors**

<u>Paint/pigment properties:</u>

3. **Active inhibition, barrier properties and adhesion**
4. **Paint adhesion strength and mechanism**
5. **Inhibitor activation and transport in the primer layer**

<u>System level:</u>

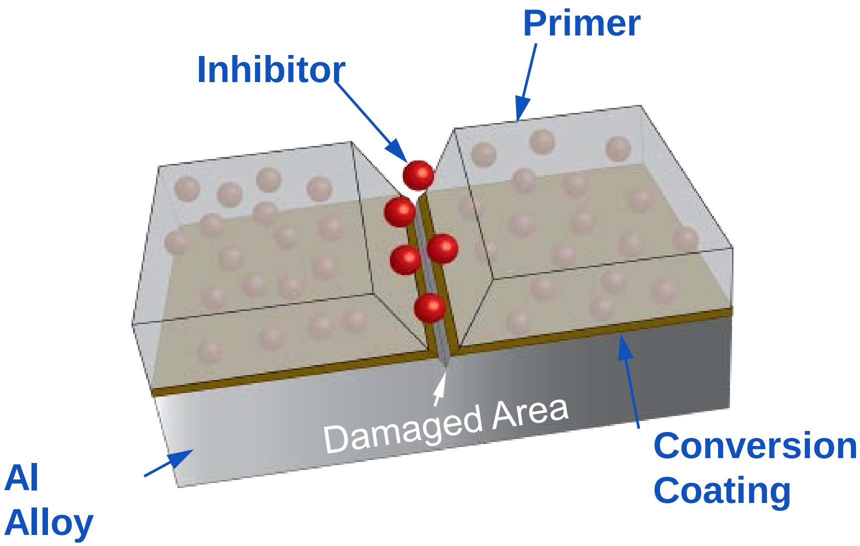
6. **Interactions between polymer matrix, pigment, surface treatment, and alloy**
7. **Characterization of local environments in coating systems**

The tasks will be performed in parallel by various team members.

Interactions between polymer matrix, pigment, surface treatment, and alloy

Background

- In chromated coating systems, chromate released from $SrCrO_4$ pigment dissolution in a primer layer, stabilized the artificial passivity of an underlying chromate conversion coating.
- Such a cooperative may not exist in arbitrary combinations of non-chromate passivation treatments and non-chromate primers or paints.



Questions:

- How well is the artificial passivity conferred by TCP, NCP and REM coatings reinforced by inhibitors leached from chromate-free pigments in overlying organic coatings?

Approaches:

- Interrupted exposure testing, in situ EIS and destructive forensic characterization at local defects.

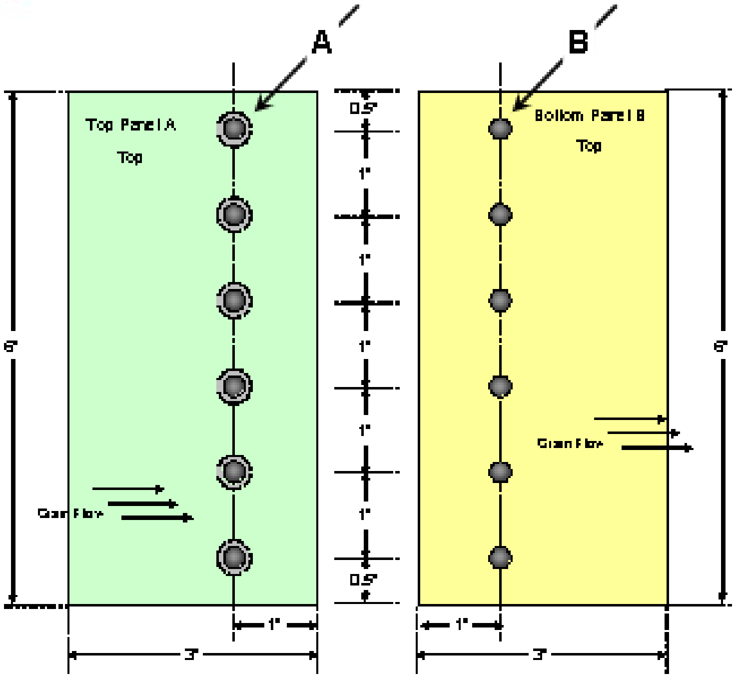
Accelerated Dynamic Corrosion Test Method Development (SERDP Project WP-1673, SwRI)

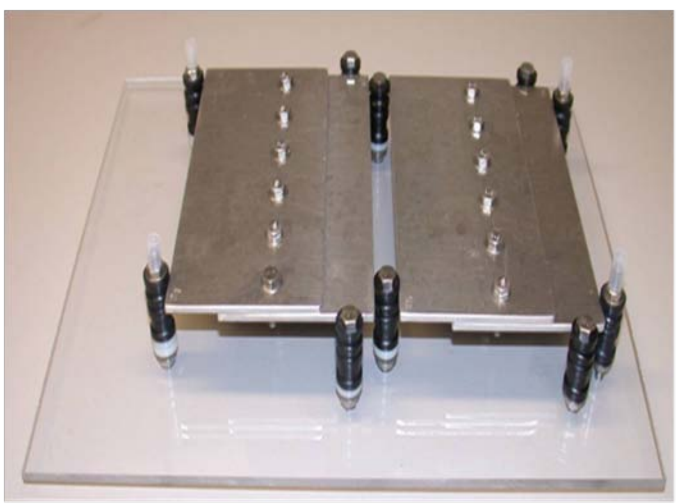
- **Objective**
  - ♦ Develop an improved test method to assess corrosion of new systems
    - Excite appropriate failure modes
    - Integrate representative sample designs into accelerated corrosion testing
    - Integrate mechanical loading into accelerated corrosion testing
- **Approach**
  - ♦ Characterize and compare the development of corrosive electrolytes for “real world” and current accelerated corrosion tests
  - ♦ Determine the effect of critical environmental and mechanical parameters on degradation modes of system components
  - ♦ Develop a framework to tailor the accelerated corrosion test to real world failure modes

Project Team

- James Dante, Southwest Research Institute
  - PI, electrochemistry, atmospheric corrosion, corrosion test method development
- Craig Matzdorf, NAVAIR Pax River
  - Co-PI, atmospheric testing, accelerated corrosion testing, qualification
- Dr. Joseph Osborne, The Boeing Company
  - Co-PI, coating system integration, coating and surface prep development, Cr and Cd replacement
- Drs. Robert Kelly and Bill Keene, University of Virginia
  - Measurement of thin film and localized electrolytes, electrochemistry, corrosion mechanisms
  - Atmospheric chemistry
- Brian Placzankis, Army Research Lab
  - Accelerated corrosion testing, materials qualification
- Steve Carr, Army Aviation and Missile Command
  - Accelerated corrosion testing, materials qualification
- Francine Bovard, Alcoa Corporation
  - Corrosion test method development, SAE Task Leader for accelerated aluminum corrosion test
- Fritz Friedersdorf, Luna Innovations Inc.
  - SCC sensors and coating properties

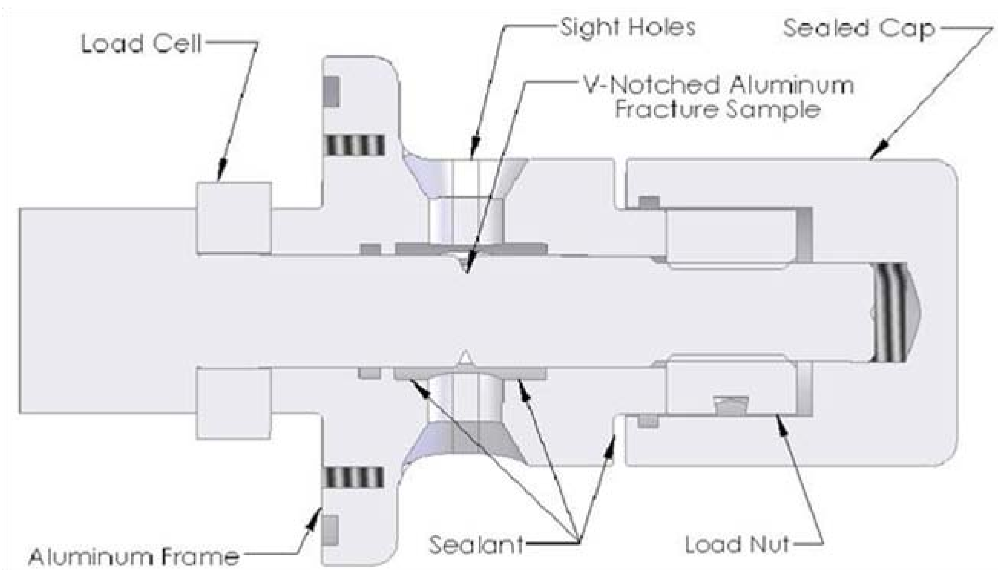
Sample Design

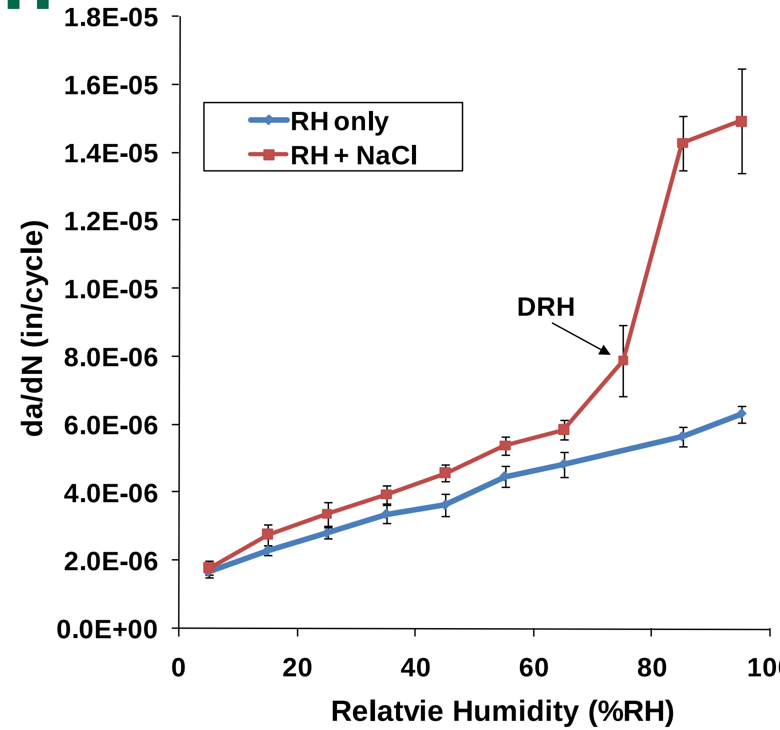




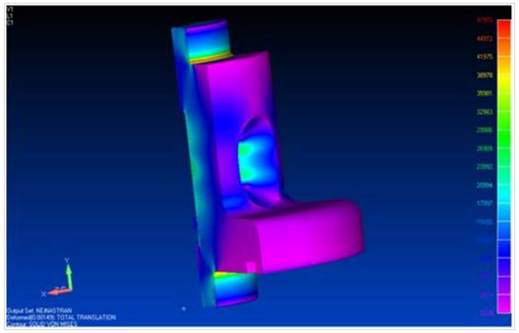
- **Sample design needs to simulate:**
  - ♦ **Geometry with exposed and occluded areas**
  - ♦ **Galvanic couples between substrates and fasteners**
  - ♦ **Coating across discontinuities**
  - ♦ **Coating defects**
- **Sample design needs to allow for:**
  - ♦ **Selection of paint, fastener materials, and substrate alloys**
  - ♦ **External mechanical loading**
- **Initial design based from NAVAIR sample geometry**
- **Working to develop guidelines and definitions for selection and characterization of exposed panels**

Effect of Environment on Cracking





- RH and NaCl effect SCC behavior
- SCC sensor being modified for measuring SCC in outdoor or laboratory environments



Selected ESTCP Projects Related to Cr^{6+}

- **FY2000:** ***Non-chromate Aluminum Pre-treatments*** **(NAVAIR Pax River)**
- **FY2003:** ***Development of Ferrium S53 High-Strength, Corrosion-Resistant Steel,*** **(Hill AFB)**
- **FY2005:** ***Validation of Novel Electroactive Polymers as Environmentally Compliant Coatings for Replacement of Hexavalent Chromium Pretreatments*** **(NAVAIR China Lake)**
- **FY2006:** ***Supersonic Particle Deposition for Repair of Magnesium Components*** **(Army Research Lab)**
- **FY2006:** ***Low Temperature Powder Coatings*** **(Hill AFB)**
- **FY2008:** ***Ultraviolet Curable Powder Coatings*** **(AFRL)**
- **FY2008:** ***Ultraviolet Curable Coatings for Aerospace Applications*** **(Hill AFB)**
- **FY2009:** ***Validation/Demonstration of Anti-Corrosion Inhibitor Primer Formulations as Replacements for Hexavalent Chromium Military Primer Coatings*** **(NAVAIR China Lake)**

Selected ESTCP Projects Related to Cr^{6+}

- **FY2009:** ***Non-Chromate, ZVOC Coatings for Steel Substrates on Army and Navy Aircraft and Ground Vehicles*** **(ARL)**
- **FY2009:** ***Electrodeposition of Nanocrystalline Co-P Coatings as a Hard Chrome Plating Alternative*** **(NAVAIR Jacksonville)**
- **FY2010:** ***Electrocoat Process for Non-Chromate Primers in DoD Manufacturing*** **(NAVAIR Pax River)**
- **FY2011:** ***Chromium Elimination and Cannon Life Extension*** **(Benet Weapons Lab)**
- **FY2011:** ***Comprehensive Evaluation and Transition of Non-Chromated Paint Primers*** **(NAVAIR Pax River)**

Development of S53 Ultra-High-Strength (UHS) Corrosion-Resistant Stainless Steel

- **Ultimate objective was to develop UHS stainless steel to replace UHS low-alloy steels such as 4340 that require cadmium plating and Cr^{6+} post treatment for corrosion protection**
- **Started as SERDP Exploratory Development (SEED) project in December 1999; SERDP full project started in June 2001**
- **Transitioned to ESTCP project in March 2003**
- **Developed under Accelerated Insertion of Materials (AIM) program**
- **First military component (A10 drag brace) fabricated in December 2005**

Demonstration Tests at Hill AFB

A-10 Main Landing Gear Piston

- Performed landing gear strut testing of S53 Main Landing Gear Piston to qualification standards per Mil-A-8866 - Successfully Completed 4 Lifetime Test
- Conduct a Field Service Evaluation with fully processed components on an A-10 aircraft - Awaiting Approval

A-10 Nose Landing Gear Drag Brace

- Perform landing gear strut testing of S53 Main Landing Gear Drag Brace Strut to qualification standards per Mil-A-8866 - Complete
- Conduct a Field Service Evaluation with fully processed components on an A-10 aircraft - Awaiting Potential Approval

A-10 Nose Landing Gear Axle

- Analysis and Design to Achieve Final Qualification - Complete
- Conduct a Field Service Evaluation with fully processed components on an A-10 aircraft - Awaiting Potential Approval

T-38 Piston

- Performed landing gear strut testing of S53 Main Landing Gear Piston to qualification standards per Mil-A-8866 - Successfully Completed 5 Lifetime Test
- Conduct a Field Service Evaluation with fully processed components on a T-38 aircraft - December 2010

A10 Demonstration Components

A-10 main landing gear piston (4330V – 240 ksi)
More complex loading
Forged component

A-10 drag brace (300M - 270 ksi)
Simple tension loading
No forging required
Corrosion related failures

A-10 nose landing gear axle

Examples of *Ferrium* S53® Market Adoption

Application Examples

- Aircraft landing gear - parts in production and preparing for flight by USAF; commercial landing gear parts in detailed evaluation
- Auxiliary aircraft equipment - parts specified for use in major next-generation commercial aircraft platform aux equipment
- Motion control devices - parts specified for aerospace platforms
- Drive shafts - demonstration helicopter rotor driveshafts in progress
- Extensive market qualifications/property data resources -
  - CINDAS ASMD data base
  - MMPDS-04 CN1
  - SAE AMS 5922
- Robust supply chain -

  2 competing licensees:

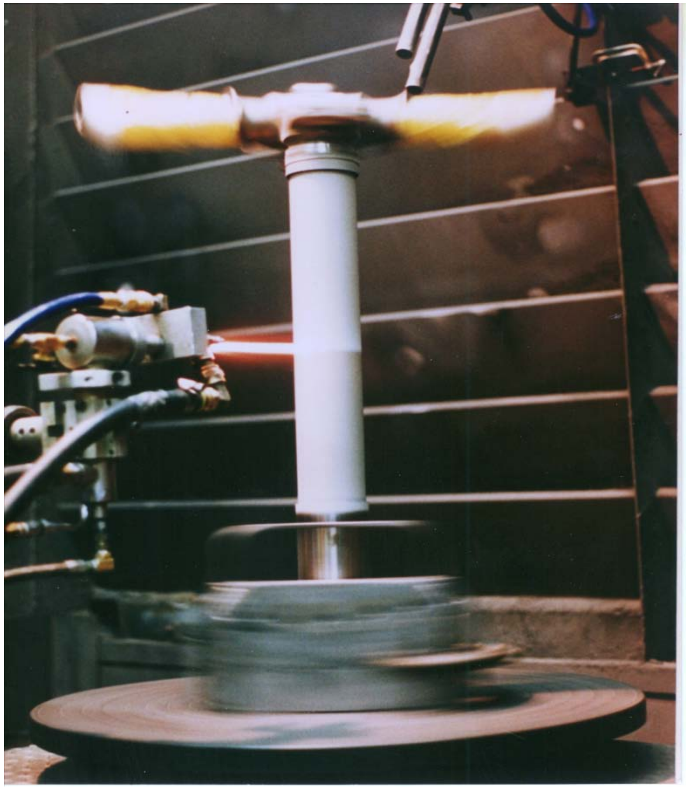
CARPENTER

LATROBE SPECIALTY STEEL COMPANY

Qualification of HVOF Coatings on Different Types of Aircraft Components

- **Separate ESTCP projects were executed for EHC replacement related to:**
  - ♦ **Landing Gear**
  - ♦ **Propeller Hub Components**
  - ♦ **Hydraulic Actuators**
  - ♦ **Gas Turbine Engine Components**
  - ♦ **Helicopter Dynamic Components (rotor heads, transmissions, gearboxes, etc.)**
- **Projects ran from 1996-2006**

HVOF Thermal Spraying of WC/17Co onto nose landing gear cylinder



HVOF Implementation - Military aircraft

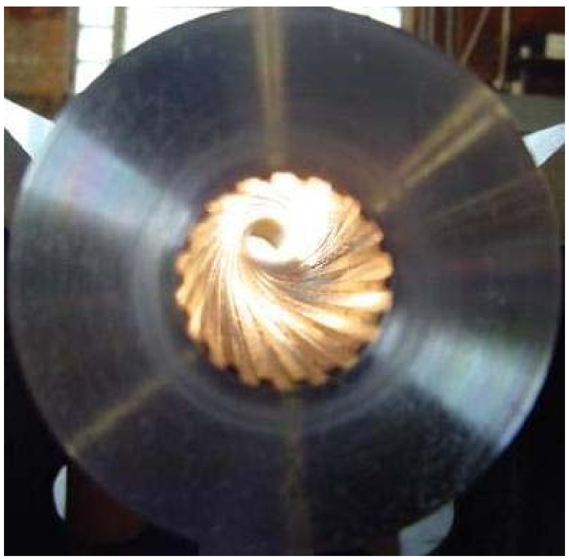
- Joint Strike Fighter (F-35) landing gear – all variants
- Hill Air Force Base (Ogden Air Logistics Center) putting HVOF into production on hundreds of landing gear components on various types of aircraft; requiring vendors to provide HVOF on landing gear, not hard chrome
- Boeing X-45C UCAV has some HVOF WC-CoCr coated landing gear components
- F-18 steering covers and shock absorber piston heads with Tribaloy 400
- CH-53 blade damper internal-surface coatings of Tribaloy 400 have been approved
- C-17 nose landing gear post: HVOF WC-Co has replaced hard chrome to prevent heat-burning
- F-22 convergent nozzle actuators: shafts coated with WC-Co, internal surfaces coated with Tribaloy 400 alloy.

HVOF Implementation – Commercial Aircraft

- All new Canadian landing gear designs specified with HVOF WC-CoCr
  - 4 HVOF shops set up to meet demand
- In commercial use for
  - Boeing 767-400
  - Boeing 787
  - Airbus A380
- Maintenance, Repair and Overhaul
  - Boeing has approved for thickness < 0.015”
  - Delta now using for maintenance
  - HVOF now used for repair of flap tracks

Eliminating Chromium from Medium Caliber Gun Barrels

Team: Benet Laboratories, Army Research Laboratory, Ares Inc., High Energy Metals, Inc., TPL, Inc., General Dynamics ATP



Results

- Process to explosively bond Tantalum-10% tungsten liners to the insides of medium caliber cannons.

- Firing tests demonstrated that the lined tube showed superior wear resistance – lasts twice as long as chrome-plated tube.

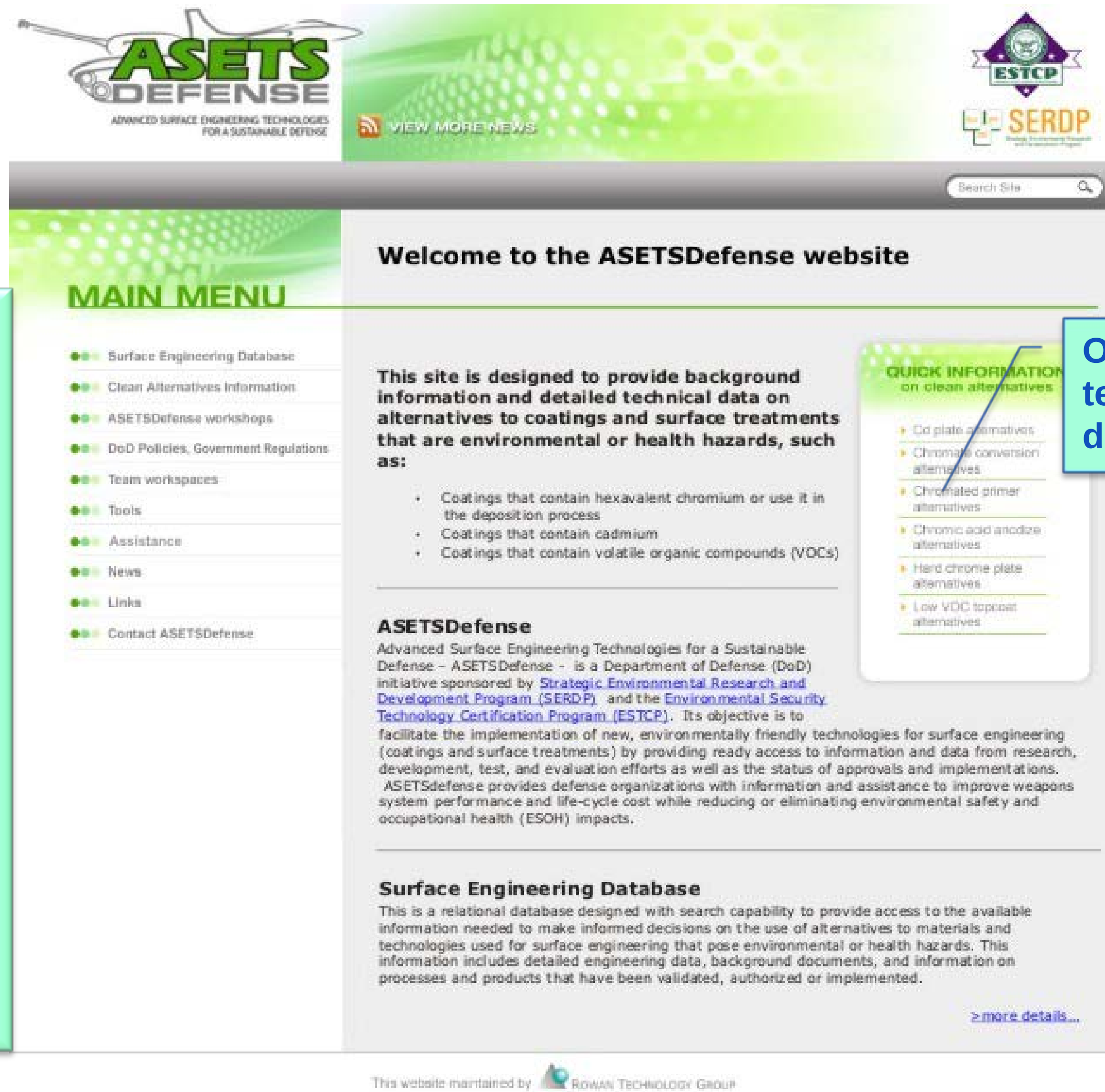
Benefits

- Eliminates the use of hexavalent chromium in medium caliber gun barrels while providing superior performance and reduced life cycle costs.

SERDP/ESTCP Initiative

- Numerous surface-engineering-related projects executed by SERDP, ESTCP and other organizations to develop and evaluate new technologies that are more environmentally friendly and reduce life-cycle costs
- Problem is that stakeholders and weapons systems owners do not have ready access to data to determine if new technology can be implemented
- ASETSDefense is initiative intended to develop information data bases and organize workshops associated with technologies in the surface engineering field; web site www.asetsdefense.org is entry point to engineering data and materials selection data bases under development

www.asetsdefense.org



Menu

- Surface Engineering Database
- Clean Alternatives Information
- ASETSDefense Workshops
- DoD Policies, Government Regulations
- Team Workspaces
- Tools
- Assistance
- Links
- Contact ASETSDefense

Submenus drop down on click

One-page technology descriptions

ASETSDefense Workshop

- Held 7-10 February 2011 in New Orleans, LA
- 241 attendees representing DoD labs and repair facilities, OEMs, and vendors
- Covered all ESOH coating and surface finishing issues in new and legacy aircraft, vehicles and ships
- Focus was on Cr^{6+} as a result of USD (AT&L) memo
- 51 presentations covered research & development, demonstrations and implementations of alternative technologies
- Held side meeting on *Computational and Data Base Methods for Design and Prediction*
- Workshop summary plus all presentations are available on web site, www.asetsdefense.org
- Next workshop planned for August 2012

Information Resource

For additional information on all SERDP and ESTCP projects, visit the new SERDP-ESTCP web site:

www.serdp-estcp.org